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Article

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Performance of a hydrokinetic turbine using a theoretical approach

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Abstract

Regarding the interest in renewable energies, several sources of energy production have been studied and still under improvement. In this work, we are interested in harnessing marine energy currents exploiting the hydrokinetic turbines. The purpose of this study is to provide a comprehensive assessment of the hydrodynamic loads of a 3-blade horizontal-axis marine turbine using a rotor model adapted to the Moroccan potential. For that, the Blade Element Momentum (BEM) is used to calculate the hydrodynamic loads, to estimate the energetic performance, and to determine the blade optimal parameters for a turbine. In additions, the resulting equations are solved in order to obtain the hydrodynamic loads. For validation, a comparison of pressure coefficients along the chord length was made with the results of the Blade software. The Computations were accomplished for a specific NACA profile.

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Keywords: Marine current turbine; BEM theory; Hydrokinetic turbine; Hydrodynamics performance

1. Introduction

Due to the increasing prices of fossil fuels, renewable energy became the first solution adapted by several communities for reducing the electrical invoice. Various types are used for producing electricity from many sources. In the last decades, a big interest is given to the blue energy (energy coming from the ocean) especially for marine current energy, named also tidal stream energy, due to its potential, predictability and reliability [1].

The electrical energy is extracted from marine current using many kinds of Hydrokinetic Turbine investigations [2], which can find the hydrokinetic turbine with horizontal axis.

The HKT is falling into the category of similar lift–drag devices using the hydrodynamic blade shapes for deriving the power of the marine current and convert it to the electrical power [3].

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The prediction of hydrodynamic performances makes it possible to know the quality of the HKT to capture the energy contained in the marine currents. all the critical performance elements of the HKT and permitting to design it properly, such as the Many methodologies are used to describe vortex method [4], the computational dynamics method CFD [5] and the most used approach is Blade Element Momentum theory BEMT [6].

The following paper aims to predict the theoretical rotor performances, the distribution of the aerodynamic forces and to estimate the theoretical power extracted from marine current energy using the BEM approach. Furthermore, to validate the obtained results, a comparison of pressure coefficients along the chord length is made with the results of the Q-Blade software.

The present work is organized as follows: Section 2 gives briefly a short description of the BEM method and the mathematical formulation of all critical parameters. Section 3 shows the results obtained: rotor performance, distribution of chord, twist angle and the aerodynamic forces. Also in this section, a discussion is elaborated on the basis of the results obtained and the comparison with others obtained using Q-blade software. In Section 4 the conclusions and future work are drawn.

2. Nomenclature

BEMT	Blade element momentum theory
HKT	Hydrokinetic turbine
Cl	Airfoil lift Coefficient
Cd	Airfoil Drag Coefficient
dN	The normal force
dT	The tangential force
dQ	The torque
W	The resulting water velocity
Ω	Angular speed
C	The chord
V	The tidal stream velocity
φ	Angle of follow
β	Pitch angle
α	Angle of attack
ρ	Water density
R	The radius
K	Number of blade
λ	The tip speed ratio
Cp	Power coefficient
P	Aerodynamic power

3. Materials and methods

3.1. BEM approach

The elaboration of hydrodynamic performance of the blade is a complex task due to its rotary motion, which creates a three-dimensional flow of water around the blade of the rotor. The BEM is one of the most useful approaches for the analysis and design of hydrokinetic turbines rotor in order to determine the hydrodynamic performance and aerodynamic forces. It is a combination between the momentum theory and blade element theory. The first approach is used to elaborate the energy extracted formulation. However, the second one is used to model the section drag and torque by dividing the rotor blade into a number of elemental sections [1].

The application of the BEM theory means that at each blade radius, the rotor power loads are determined by matching the variations in the amount of fluid motion with the blade forces as a function of the lift and drag coefficients (CL and Cd) at the angles of attack of the rotor.

3.2. Mathematical formulation

The hydrodynamic performances, the distribution of the chord and the aerodynamic forces equations are obtained by employing all assumptions related to both momentum and blade element theories approaches, and the blade geometry.

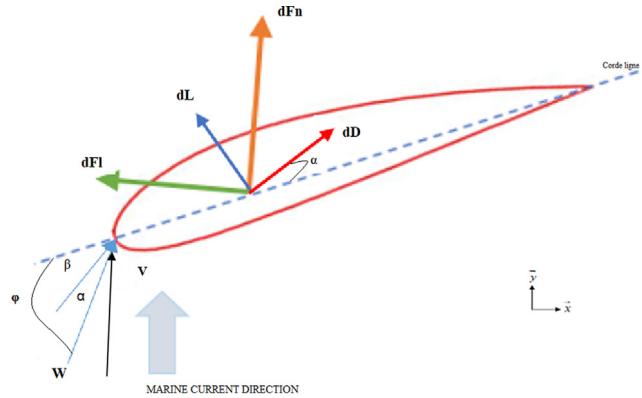


Fig. 1. The hydrodynamic forces applied to the blade element.

The equations of the rotor performances are:

- The chord

$$c(r) = \frac{8\pi r_i}{KC_1}(1 - \cos \varphi_i) \quad (1)$$

- The normal force

$$dN = \frac{1}{2}\rho\omega^2(C_l \cos \varphi + C_d \sin \varphi)cdr \quad (2)$$

- The tangential force

$$dT = \frac{1}{2}\rho\omega^2(C_l \sin \varphi - C_d \cos \varphi)cdr \quad (3)$$

- The Torque

$$dQ = rdT \quad (4)$$

$$dP = \omega dT \quad (5)$$

- The power coefficient

$$C_p = \frac{P}{P_{\text{currentmarine}}} = \frac{\int_{r_0}^R \Omega dT}{\frac{1}{2}\rho R^2 V^3} = \frac{8}{\lambda^2} \int_{\lambda_0}^{\lambda} F \lambda_r^3 a'(1-a) \left[1 - \frac{C_d}{C_l} \tan \varphi\right] d\lambda_r \quad (6)$$

4. Results and discussion

In order to evaluate the performance of the hydrokinetic turbine, the hydrofoil profile must carefully be designed. In this work, the blade profile considered is the NACA 63 421hydrofoil. The design parameters are mentioned in [Table 1](#).

Table 1. Table of parameters.

Parameters	Sign	Value
Number of blade	K	3
Radius	R	5 [m]
Tips speed ratio	λ	5.23
Velocity of water	v	1.25 [m/s]
Hub radius	r_0	0.925[m]
Rational frequency	N	15 [tr/min]
Water density	ρ	1025 [kg/m ² /m]

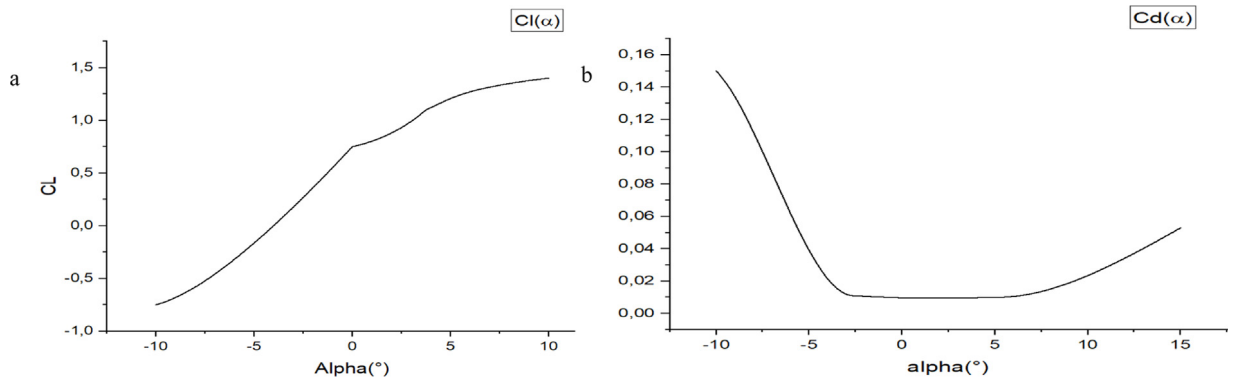


Fig. 2. The lift and drag section data using X-Foil. (a) Lift forces and (b) Drag forces.

The hydrodynamic parameters the lift, drag are solved using X-Foil software, and presented on Fig. 2.

The lift and drag coefficients curves obtained for the NACA 63–421 profile indicate that a severe flow separation occurs after 5°.

The BEM approach is applied to predict the rotor performance, to calculated distribution for the chord and the twist angle (see Fig. 2).

The chord distribution obtained shows that the blade shape is hyperbolic as shown in Fig. 3. However, in practice, these distributions are not respected because of manufacturing difficulties. So the used solution is the linearization of the chord distribution without sacrificing a lot of energetic performance.

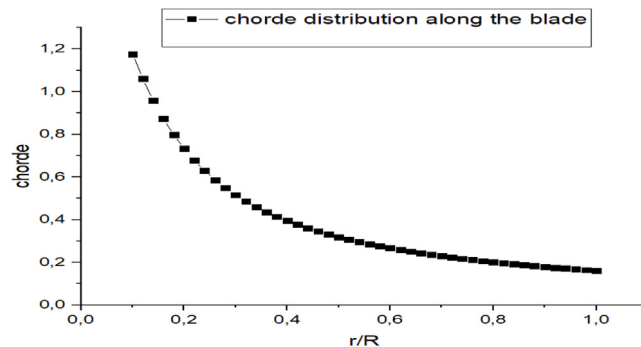


Fig. 3. The chord distribution along the blade.

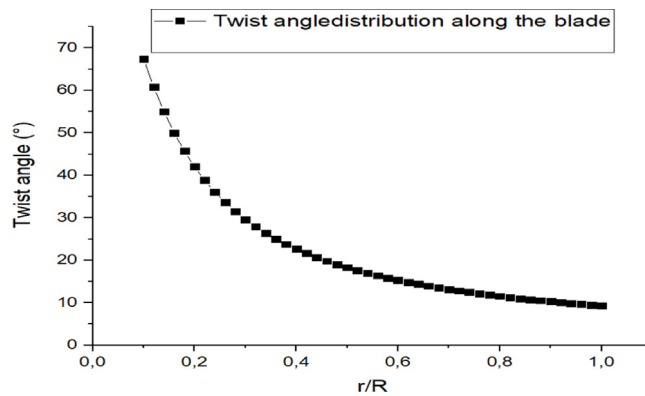


Fig. 4. The twist angle distribution along the blade.

The calculation of the power coefficient requires the derivative of Eq. (6). Fig. 5 shows the rotor performance coefficient C_p at different Tip speed ratio (TSR) at current velocity $V=1.25$ m/s.

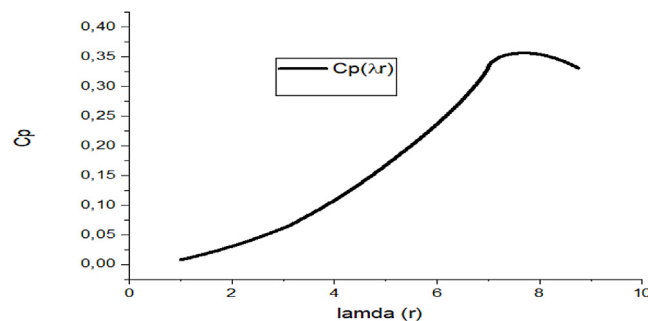


Fig. 5. The theoretical Power coefficient.

Once the performance hydrodynamic are determined, it is now possible to calculate the forces and moments acting on the blades as well as the power extracted by the propeller as in Figs. 6 and 7.

The results of the performance of the model turbine from BEM approach is compared with the Q-blade software as in Fig. 8.

5. Conclusion

The marine current energy possesses a huge potential to produce electricity. To successfully harness it, the rotor must be designed carefully. The BEM approach has been employed and presented in this article in order to predict the rotor performances. The rotor has an efficiency of 33% at the rated speed 1.25m/s. The results obtained allow the rotor to maintain its efficiency at a varying tip speed ratio which is very hard to found. Also, they are compared with those of Q-blade software. The hydrodynamic forces obtained will be used to analyze the structure of the rotor which is the goal of the next work.

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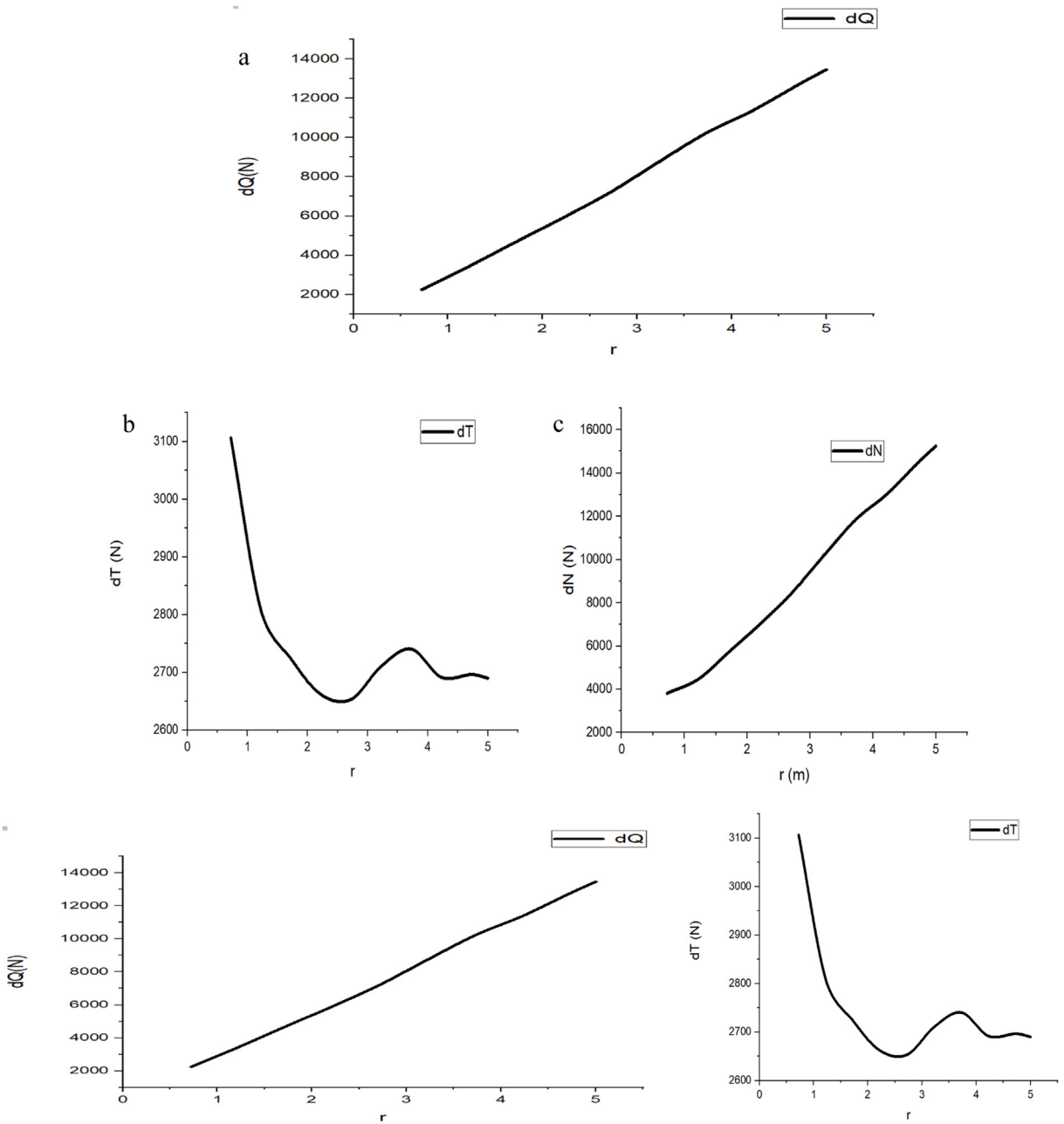


Fig. 6. The hydrodynamic Performances (a) the Torque force (b) The tangential force (c) The normal force.

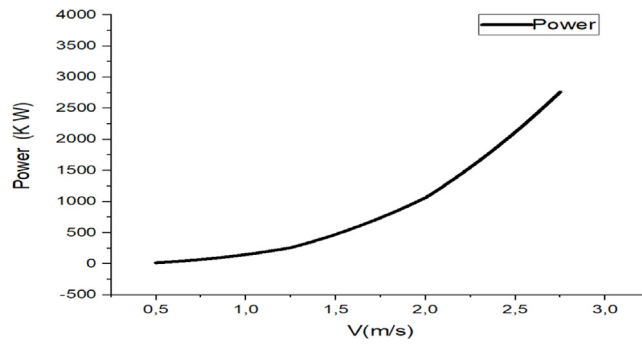


Fig. 7. The power output at different speeds.

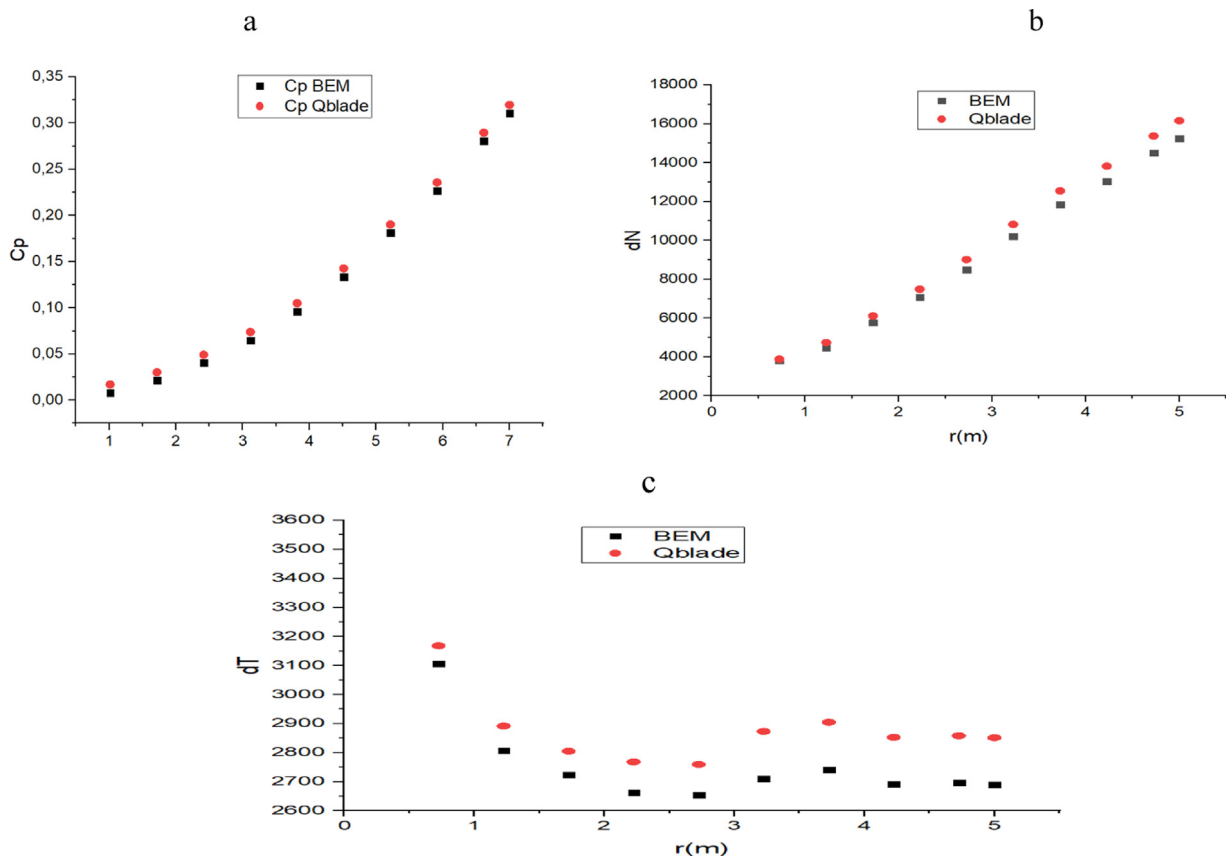


Fig. 8. The comparison between the results obtained from BEM et Q-blade (a): Cp, (b): Normal force, (c): The Tangential force.

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